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t. SEMI-ANNUAL STATUS REPORT
FOR THE PERIOD JUNE 1, 1963 - NOVEMBER 30, 1963
ON
INVESTIGATION OF CERAMICS AS STRUCTURAL MATERIALS

Project Staff: F. R. Shanley,
W. J. Knapp,
R. D. Chipman,
M. A. Ali,
George Nikolaychik, and
David Weiss

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Department of Engineering
University of California
Los Angeles 24, California

U. Los Angeles

0524 702

FOREWORD

The research described in this report, Semi-Annual Status Report for the Period June 1, 1963 - November 30, 1963 on Investigation of Ceramics as Structural Materials, was carried out under the technical direction of F. R. Shanley and W. J. Knapp and is part of the continuing program in Analytical and Experimental Investigation of Ceramic Materials for Use as Structural Elements.

This project is conducted under the sponsorship of the National Aeronautics and Space Administration, Office of Space Sciences, Washington 25, D.C.

Submitted in partial fulfillment of Contract Number NsG-427.

ACKNOWLEDGEMENTS

The interest and assistance of the International Pipe and Ceramics Corporation, Los Angeles, in fabricating and donating ceramic plates for this research, are gratefully acknowledged. Earlier support also was provided by Interpace (then Gladding McBean and Company) for the study of a biaxially-prestressed ceramic slab.

Appreciation also is expressed for the advice and assistance of Dr. G. M. Butler, Jr., Mr. S. V. Saginor, and Dr. M. S. Troitsky.

ABSTRACT

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Prior research, aimed at the successful use of ceramics as structural materials, and mainly utilizing the technique of prestressing, is reviewed. The objectives of the present research program are presented. Current investigations are concerned with the strength of cellulated ceramics, the effects of uniaxial and biaxial prestressing, the load-deflection characteristics of a prestressed ceramic slab, and the fabrication of a prestressed ceramic dome.

Author

I. INTRODUCTION

Over ten years ago Professors F. R. Shanley, W. J. Knapp and R. D. Chipman began a joint program of study aimed at the successful use of ceramics as structural materials. The early studies were carried out without outside sponsorship. These led to two basic methods of attack, as follows:

1. Eliminate or greatly reduce tensile stresses by the technique of prestressing.*
2. Improve the ductility of the ceramic material by some method of facilitating internal slip, still retaining a substantial part of the desirable high-temperature properties.

These two programs were attacked simultaneously, but only the first one is pertinent to the work to be described in this report.

Prestressed Ceramic Structures (Background)

An outstanding limitation of ceramics, for structural applications, is their relatively low strength under tensile loads. This characteristic is, of course, inherent with the lack of plasticity of ceramics at room temperature.

Therefore, it seems clear that the successful use of ceramics for structures can be extended by the technique of prestressing. Prior research with prestressed ceramic members has been carried on in the Department of Engineering, UCLA, and includes studies of the structural characteristics of prestressed cantilevered beams, a biaxially-prestressed ceramic slab, and several prestressed model wing members. In addition, the effect of prestressing a ceramic material on its resistance to failure by thermal shock was investigated; marked improvement in resistance to failure under a specified thermal stress was shown. A more complete review of the above research is given in Reference 2.

* In concrete, "prestressing" usually means pretensioning the cables before the concrete is poured; "poststressing" means tensioning the cables after the concrete has hardened. The general term "prestressing" will be used here.

II. RESEARCH PROGRAM

Based on previous experience, the following investigations are in progress:

- (1) Effects of directional cellulation on the strength of a ceramic material.
- (2) Effects of uniaxial and biaxial prestressing on the load bearing capacity of ceramic plates.
- (3) Analytical and experimental study of the load-deflection characteristics of a ceramic slab under biaxial prestressing.
- (4) Fabrication and testing of a prestressed ceramic dome.

In addition, a review of the literature has been completed to ascertain the extent of pertinent prior work related to ceramics as structural elements. A digest of this review will be presented in a forthcoming summary report.

III. STATUS OF INVESTIGATIONS IN PROGRESS

(1) Effects of Directional Cellulation

One of the unreachd goals in refractory development is the manufacture of a ceramic which possesses both high-strength and light-weight characteristics. The realization of such a material is of particular significance where pre-stressed ceramic structures are concerned. The research proposed herein suggests an approach to the development of a ceramic with these features.

When ceramic materials are cellulated by a random distribution of closed pores, their strength is reduced exponentially with increasing porosity.^{4, 5} In contrast, Shanley et al³ have discovered that the compressive load carried by a ceramic specimen from which material had been removed in the direction of loading (cored) was actually greater than the load carried by a solid specimen. This effect was noted up to 23% of the volume of material removed, with an apparent peak at 5% of material removed at which point the total compressive load was increased by 24%.

In this investigation, a number of ceramic specimens is being fabricated (by slip-casting) containing cellulations of several amounts of configurations. The load-bearing capacity of the specimens will be determined under compressive and bending loads.

The effect of the cellulation upon the load-bearing capacity of the specimen will be referred to as the "cellulation component", while the contribution of the actual material in the specimen will be referred to as the "material component". Figure 1 shows a simplified plot of compressive load-bearing capacity vs. fraction of material removed, of a ceramic specimen of unit cross-section having a solid compressive strength of 80,000 psi. The curve ABC is simplified from Shanley et al,³ and the entire curve ABCD represents the summation of the cellulation and material components. It is logical to assume that the material component will follow a straight line AD as indicated (i.e., load divided by actual material in the cross-section remains constant). For the purposes of this discussion, it will be assumed that the cellulation component consists of the two linear segments as shown in Figure 1, although in all probability such is not the case. This latter curve EFD is to be determined by this research, by experimentally determining the curve ABD and subtracting the curve AD, thereby demonstrating the effect of directional cellulation. By comparing this curve with a theoretical analysis, the reasons for this effect may be determined.

All specimens will be fabricated in the UCLA Ceramics Laboratory, under conditions which would minimize deviations in the ceramic material. It is doubtful whether more than 60% of the material may be practically removed from the ceramic material using circular cells. If rectangular cells are used, more material may be removed. In either case, the changing slenderness ratio of the columns of remaining material is expected to contribute significantly to the results at higher porosities.

The fabrication of cellulated ceramic specimens is in progress. To date, specimens have been prepared in which up to 49% of the ceramic material has been removed.

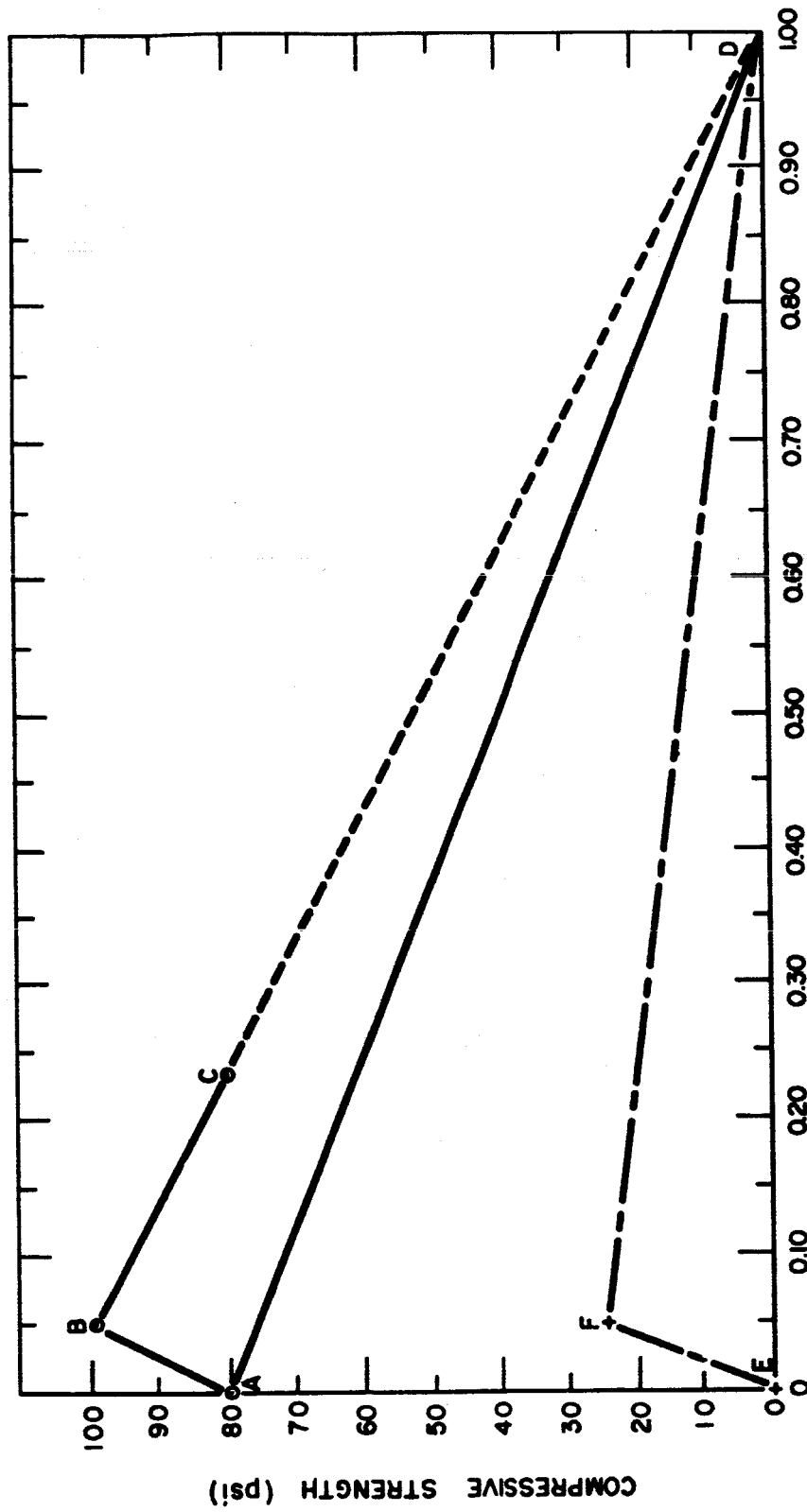


FIGURE 1

(From Shanley, et al., Reference 3)

(2) Effects of Uniaxial and Biaxial Prestressing
on Load-Bearing Capacity

Prior work has confirmed conclusively that prestressed ceramic members, of specific types and under given loading conditions, possess greatly improved load-bearing capacity. However, few, if any, previous determinations have been made of quantitative relationships between the prestress level and load-bearing capacity for specific structural members.

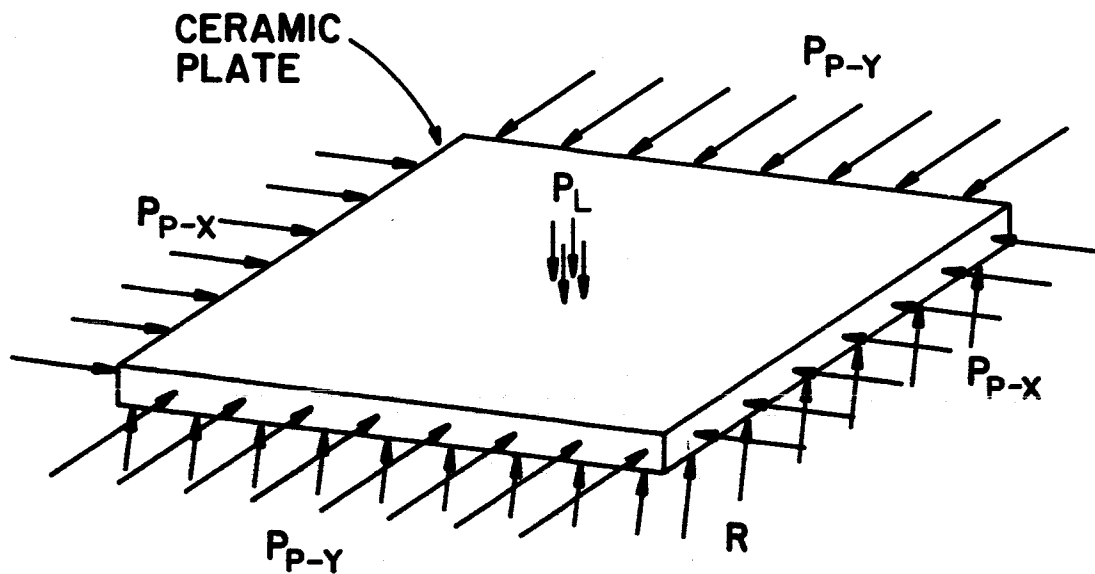
In this study, the load-bearing capacity of some ceramic plates will be determined while they are prestressed, to various levels, uniaxially and biaxially. The ceramic plates are approximately 1/2 inch x 6 inches x 6 inches in size, and have been fabricated with a clay-talc type ceramic body.*

This ceramic is a material of moderate strength (crushing strength is about 20,000 psi) and of moderate porosity. Loading of a plate is indicated schematically in Figure 2. A steel prestressing fixture, which has been designed and fabricated to permit both prestressing and load-testing, is shown in Figure 3. The prestressing loads, and the testing load, are applied by means of calibrated hydraulic jacks (two 30 ton jacks and one 10 ton jack). The fabrication of the fixture and calibration of the loading jacks have been completed, and load-testing of the ceramic plates has been initiated. Over four hundred plates are available for this study, making it possible to obtain results of some statistical significance.

(3) Load-Deflection Characteristics of a Ceramic Slab
Under Biaxial Prestressing

The concept of fabricating prestressed ceramic structures, by assembling and prestressing a number of small, discrete ceramic units, seems to be especially promising. To obtain additional information on such a prestressed member, this work involves the analytical and experimental study of the load-deflection characteristics of a biaxially-prestressed slab.

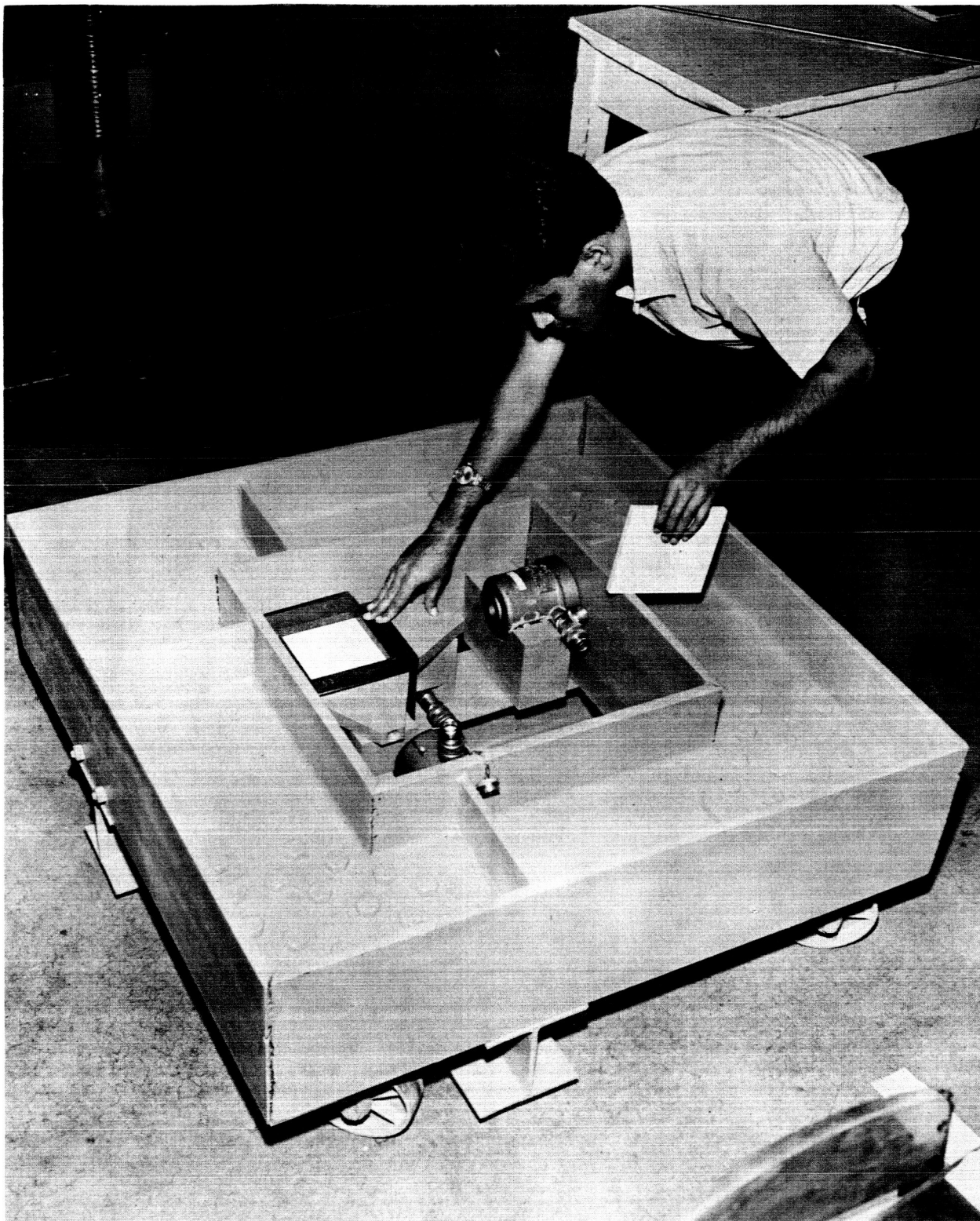
* We are indebted to the International Pipe and Ceramics Corporation, Los Angeles, for their generosity and assistance in fabricating these specimens, and in donating them to the University of California.



P_{P-X} = PRESTRESSING LOAD IN X-DIRECTION
 P_{P-Y} = PRESTRESSING LOAD IN Y-DIRECTION
 P_L = "LIVE" LOAD

LOADING OF A BIAXIALY PRESTRESSED CERAMIC PLATE

FIGURE 2



PRESTRESSING FIXTURE FOR CERAMIC PLATES

FIGURE 3

The slab being tested is a previously existing one,* which was fabricated by Professor R. D. Chipman. The slab is approximately 1 inch x 4 feet x 4 feet in size, and is comprised of specially-made ceramic units about 1 inch x 2 inches x 2 inches in size. The units were assembled, using 1/16 inch asbestos-gasketing material between the bearing surfaces, and prestressed with 3/16 inch diameter wire rope. The general nature of the slab may be seen in Figures 4, 5, and 6. The ceramic units used, when load-tested individually, showed a strength in crushing of about 20,000 psi. (Further details concerning the slab and its fabrication are available upon request.)

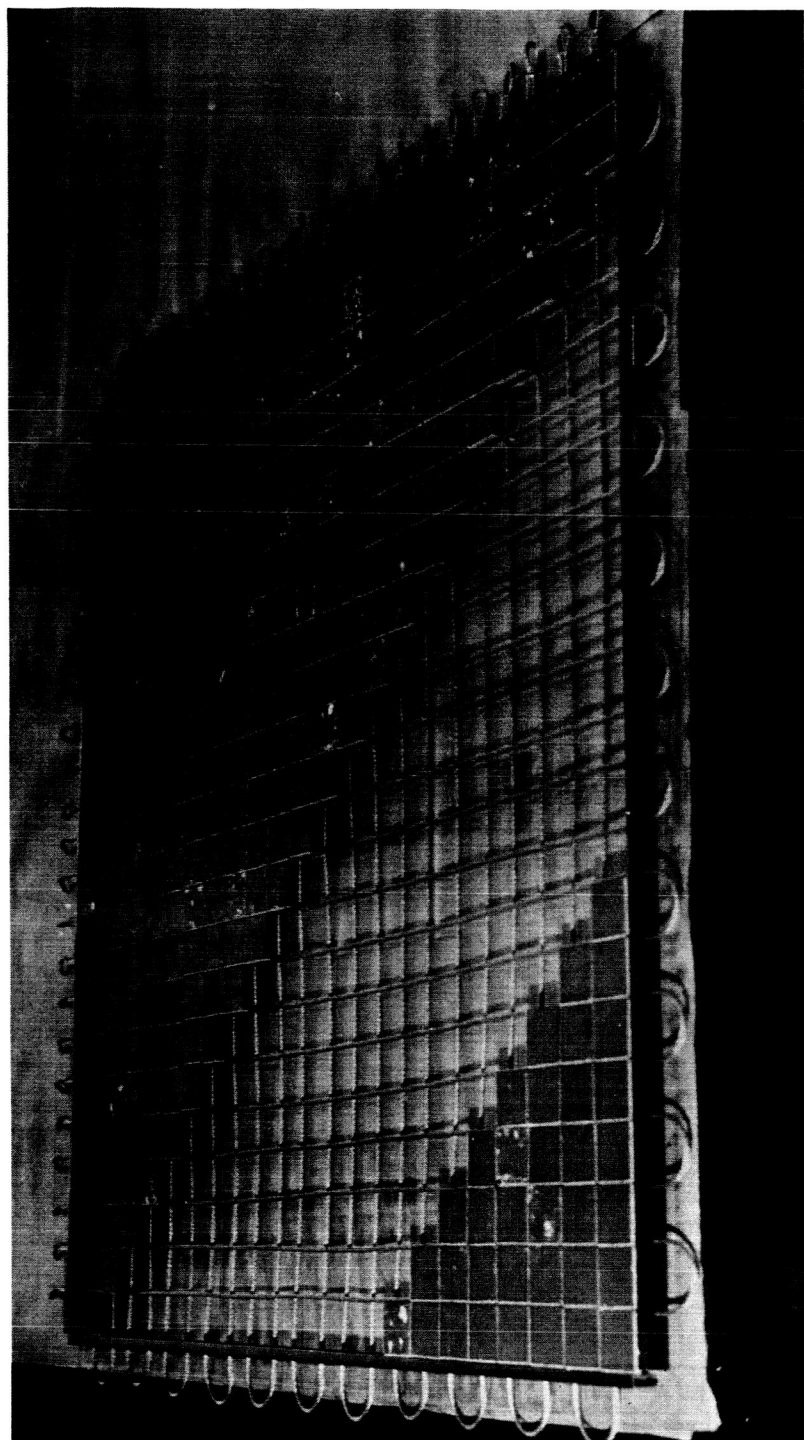
The slab is being prestressed again in preparation for testing. The study will determine the load-deflection characteristics of the slab, and will attempt to answer questions like:

- (a) What is the behavior of the slab throughout the elastic range of loading?
- (b) How does the slab deflect as a function of prestress and surface loading?
- (c) What is the distribution of strain, stress and moment on the slab under various loading conditions?

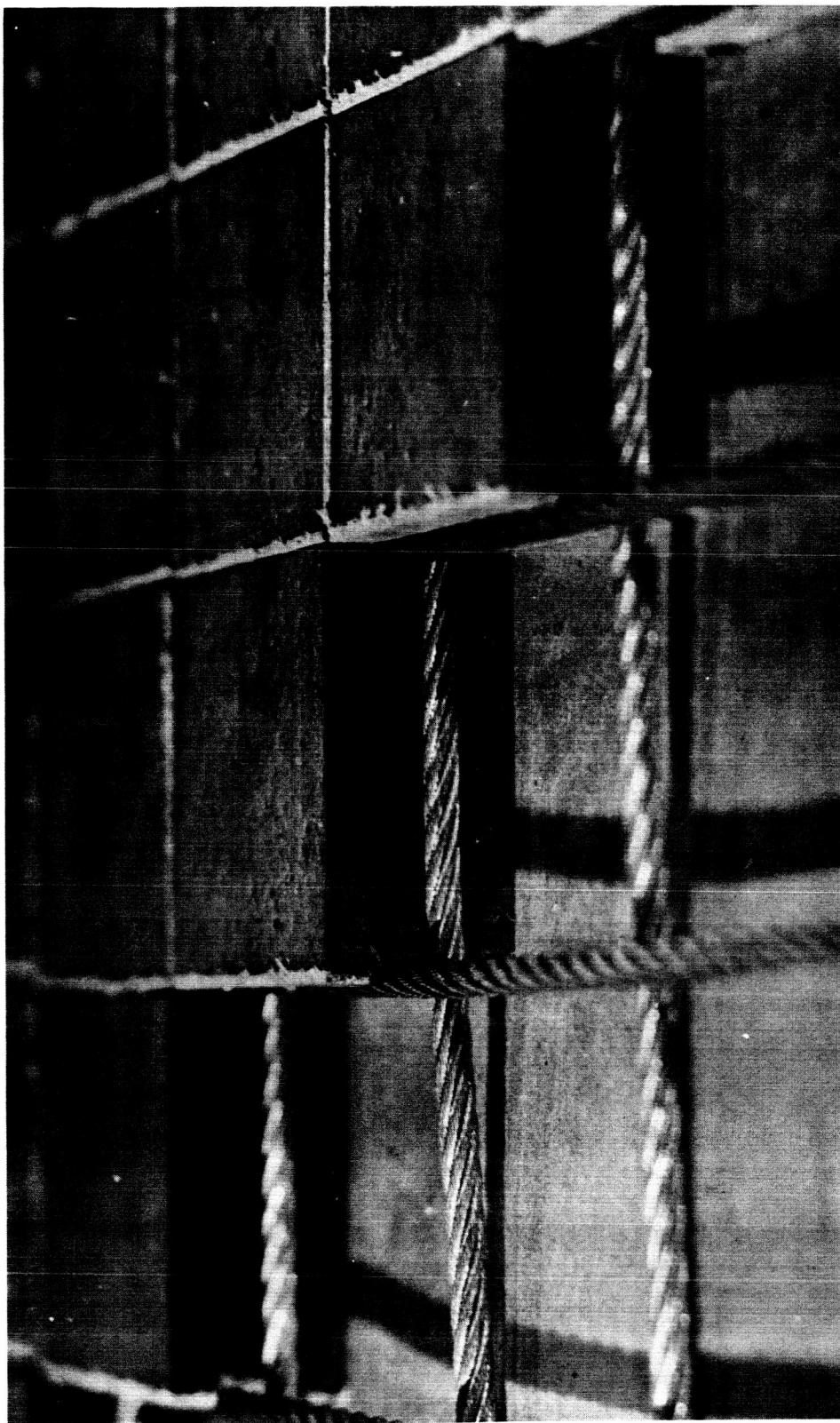
(4) Fabrication and Testing of a Prestressed Ceramic Dome

The fabrication of prestressed structures with single and double curvature is a challenging objective. It is believed that it may be feasible to assemble and prestress a number of small ceramic units, in a manner similar to that used for the slab described under (3), to fabricate a structure with curvature. Preliminary planning has been made for the fabrication of a small model dome with a ceramic material. Slip-casting will be used for forming the ceramic material.

* We gratefully acknowledge the prior assistance of the International Pipe and Ceramics Corporation (then Gladding McBean and Co.) in preparing ceramic units and in providing financial support.



FABRICATION OF A CERAMIC SLAB
FIGURE 4



DETAIL OF SLAB CONSTRUCTION
FIGURE 5



BIAXIALLY PRESTRESSED CERAMIC SLAB
FIGURE 6

This work is concerned at present with the design of a mold for fabricating the ceramic material, and with planning of a technique of prestressing. If a ceramic dome can be successfully prestressed, load-testing will be carried on.

IV. SUMMARY

The studies in progress under this project are to a considerable extent the outgrowth of earlier research with prestressed ceramics in the Department of Engineering, UCLA. Current investigations are concerned with the strength of cellulated ceramics, the effects of uniaxial and biaxial prestressing, the load-deflection characteristics of a prestressed ceramic slab, and the fabrication of a prestressed ceramic dome.

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